

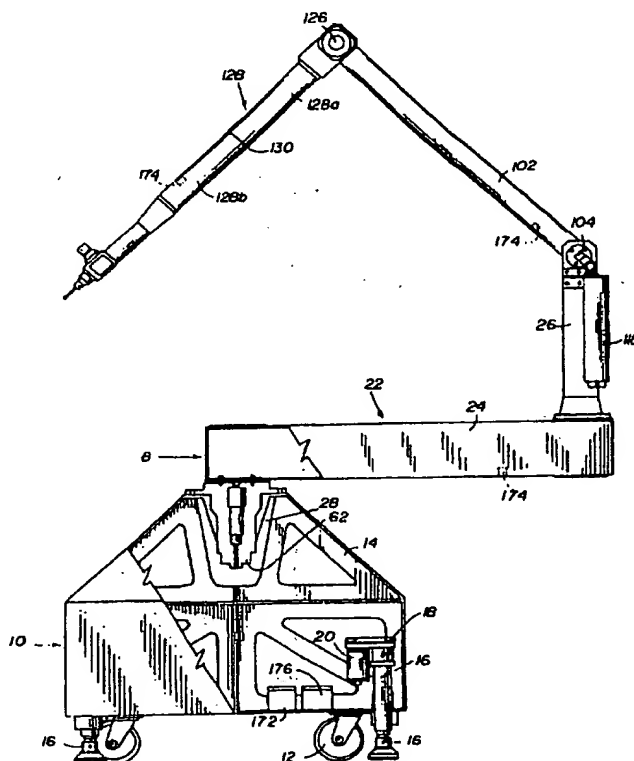
## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(21) International Application Number: PCT/CA97/00103 (22) International Filing Date: 14 February 1997 (14.02.97) (30) Priority Data: 2,183,004 23 August 1996 (23.08.96) CA (71)(72) Applicant and Inventor: CAMURRI, Nino [CA/CA]; 3365, rue Christiane, Fabreville, Laval, Québec H7P 1K5 (CA). (74) Agent: MARTINEAU, François; Bureau 700, 1440, rue Sainte-Catherine ouest, Montréal, Québec H3G 1R8 (CA).	(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).  Published With international search report.	

(54) Title: COORDINATE MEASURING APPARATUS

## (57) Abstract

This apparatus measures the XYZ coordinates of a point on a part to determine its position in space. The apparatus comprises a movable measuring assembly and a remote processing station. The assembly includes serially arranged rigid arm members pivoted by rotary joints to a wheeled base and to a probe for engaging the part. A rotary encoder is mounted at each joint for measuring the rotation angle of one arm member relative to the other; each encoder sends an analog sinusoidal signal to an associated micro-controller which comprises an analogic to digital converter and a processing unit to generate a digital signal indicative of an instantaneous rotation angle. All the controllers are connected in a network and the resultant of the simultaneous readings of all of the encoders is sent by a radio frequency transmitter mounted on the base to the remote processing station equipped with a radio receiver and a computer which processes the transmitted data into measurement coordinates. To increase the measuring precision, each micro-controller is capable of taking several instantaneous readings of the sinusoidal pulse emitted by the encoder and to calculate an average of said readings. The base has an automatic levelling device; each arm has a temperature sensor for effecting temperature compensation. Data recording is automatically stopped if the machine is subjected to excessive vibration or shocks.



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## TITLE: COORDINATE MEASURING APPARATUS

FIELD OF THE INVENTION

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The present invention relates to an apparatus for measuring the XYZ coordinates of a point on a part to determine the position of this point in space.

BACKGROUND OF THE INVENTION

15

Coordinate measuring apparatuses or machines are used to inspect products, to verify drawings specifications and tolerances and to automatically generate new drawings for reverse engineering. These machines include articulated counter balanced rigid arms with rotary position encoders at their joints that measure angular displacement from a reference point. To take a measurement, the user touches the object to be measured with a probe carried at the outer end of the articulated arm system. The 3D information provided by the encoders are digitized and transmitted to a control computer which processes the data and transforms the same into measured coordinates from a reference point. Angle measurements of the rotary encoders used on existing machines lack precision and therefore known machines have a small size and can only operate within an envelope of restricted volume; therefore known machines must be displaced several times and relocated with respect to another reference point when called upon to measure large objects.

35

Such measuring machines are often used in an environment where they are subjected to a temperature gradient. Known machines of the character described include a temperature compensation system which is not capable of adequately correcting any possible distortion

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caused by those temperature gradients. Known machines of the character described are normally connected to a control computer by a cable which on a shop floor can be damaged or can be cause of accidents and which restricts the range of movement of the machine with respect to the control computer.

### OBJECTS OF THE PRESENT INVENTION

It is therefore the main object of the present invention to provide a coordinate measuring apparatus which obviates the above noted disadvantages and more particularly which can measure with precision coordinate points within a radius of about 3 meters and even more in any direction and which can be mounted on wheels to facilitate manoeuverability.

Another object of the present invention is to provide an apparatus of the character described capable of automatic leveling independently of the floor irregularities.

Another object of the invention is to provide an apparatus of the character described which is equipped with an automatic device to detect any shocks and vibrations to the machine and which automatically stops machine operation if the shock loading or vibrations amplitudes exceeds a predetermined limit.

Another object of the invention is to provide a temperature compensation system which corrects any distortion of each arms and each joints of the machine caused by temperature gradients to which the machine would be subjected.

Another object of the present invention resides in an apparatus of the character described in which all

the collected data are transmitted from the measuring apparatus to the control processing computer by radio transmission.

5

#### SUMMARY OF THE INVENTION

The apparatus of the invention is for measuring the XYZ coordinates of a point on a part to determine its position in space and comprises a movable measuring assembly and a remote processing station, said measuring  
10 assembly comprising a base, a probe for engaging said point, serially coupled rigid arm members and rotary joints coupling said base to said probe and permitting said probe to be moved in space relative to said base,  
15 each joint including to relatively rotating parts, a rotary encoder for each joint, for measuring the rotation angle of one part relative to the other part of the joint, said encoder sending an analog sinusoidal signal of N pulses per complete rotation, a micro controller for  
20 each encoder including an analogic to digital converter and a processing unit to generate a digital signal indicative of an instantaneous rotation angle, network means interconnecting all of said micro controllers and means to transmit to said remote processing station data  
25 representing the simultaneous readings of all of said encoders, said remote processing station including a computer for receiving the transmitted data and processing the same to transform the data into measured coordinates from a reference point.

30

Preferably, the measuring assembly further includes a radio frequency transmitter connected to all of said micro-controllers via said network means, the latter including wire means extending along said arms and  
35 interconnecting all of said micro-controllers with said radio transmitter, said processing station including a radio receiver connected to said computer whereby a radio

link is established between the station and the movable assembly through which all of the measurement data is transmitted.

5                    Preferably, each micro-controller further includes sinusoidal signals sampling and holding means and means to calculate sinusoidal signal averages of successive data inputs and feeding said averages to said analogic to digital converter.

10                   Preferably, the base is mounted on wheels for displacement on a floor or the like and further including base levelling legs carried by said base and means for automatically actuating said legs to level said base.

15                   Preferably, the apparatus further includes temperature sensors for each arm member connected to each micro-controller, said micro-controller is programmed to be capable of calculating temperature correction factors  
20                   of each member and furthermore transmitty the adjusted valves to the central computer unit through the said radio transmitter.

25                   Preferably, the base is equipped with an alarm system sensitive to shock loading of said base and stopping the operation of said measuring assembly when shock loading exceeds a predetermined maximum. The shock loading system includes three accelerometers mounted on  
30                   said base along XYZ axes.

#### DESCRIPTION OF THE DRAWINGS

In the annexed drawings:

35                   Modified figure 1 is an elevation of the apparatus of the invention with the base partially in section to show the internal parts.

Modified figure 2 is top view of the intermediate arm with its end joints.

5 Figure 3 is a partial side elevation of the outer arm, the end joint and the probe.

Figure 4 is a partial vertical section of the wheel mounted base.

10 Modified figure 5 is a vertical section of the rotary joint between the base and the horizontal portion of the L-shaped arm.

15 Modified figure 6 shows the assembly of the horizontal portion of the L-shaped arm fitted with the joint of figure 5.

20 Modified figure 7 is a longitudinal section of the vertical portion of the L-shaped arm together with the rotary joints associated therewith.

25 Modified figure 8 is an elevation, partially in longitudinal section, of the stabilizing system for the intermediate arm.

30 Modified figure 9 is top view of the intermediate arm fitted with rotary joints at its two ends.

Figure 10 is a side elevation partially in section of the arm of figure 10.

35 Figure 11 and modified figure 12 are longitudinal sections of consecutive portions of the outer arm together with the probe and the rotary joints.

Figure 13 is a flow diagram showing the network

in which the several rotary encoders are connected and showing the data transmitted by radio frequency to a control computer; and

5 Modified figure 14 is a flow diagram of the micro-controller associated with each rotary encoder.

In the annexed drawings, like reference characters indicate like elements throughout.

10

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The apparatus of the invention includes a remote processing station 2, see figure 13, comprising  
15 the computer 4 and the radio receiver and transmitter 6.

The apparatus further includes a measuring assembly generally indicated at 8, the mechanical parts of which are shown in figures 1 to 11 and the electronic  
20 parts of which are shown in figures 13 and 14.

As shown in figure 1, the measuring assembly includes a base 10 mounted on caster wheels 12 which are disposed underneath a rigid framework 14 to the four  
25 corners of which are secured vertical levelling legs 16 each actuated for up and down movement by a linear actuator 18, driven by a reversible electric motor 20. The four motors 20 are interconnected in a circuit including level measuring transducers (not shown) to  
30 automatically level base 10 once the base 10 has been moved to a position ready to start measuring a part such as an aircraft wing or the like. The leveling command can be given by the operator at the remote station 2 or at the measuring assembly 8.

35

On top of base 10 is mounted a rigid L shaped arm 22 which includes a horizontal portion 24 and a



vertical portion 26. L shaped arm 22 is rotatably mounted on top of the base 10 for rotation about a vertical axis by means of a rotary joint 28 which includes an outer cylindrical housing 30 having a top flange 32 and secured by bolts 34 to the top of the framework 14. A tubular shaft 36 made of two sections, 37 and 37a welded together, the latter within the former, is located within housing 30 and two sets of ball bearings 38 and 40 respectively rotatably support shaft 36 within cylindrical housing 30. Each set of ball bearings consists of two superposed angular bearings resisting radial and axial thrusts. The outer races of the two ball bearings 38 are firmly retained between a shoulder 42 of cylindrical housing 30 and a retainer ring 44 secured to flange 32 by bolts 46. The outer races are axially spaced by a spacer ring 48. The inner race of the two ball bearings 38 are spaced from each other by a spacer ring 50 and are pressed together by a top disk 52 secured to the tubular shaft 36 by bolts 54 and by a flanged sleeve 56 surrounding and slidable relative to smaller tubular shaft section 37a and which exerts an axial action on the inner race of the two ball bearings 40 of the lower pair and which are retained in position by a washer 58 and a nut 60 screwed around the lower end of tubular shaft section 37a. It will be noted that the degree of pre-loading of the top pair of ball bearings 38 can be precisely adjusted by using rings 48 and 50 of precisely selected differential height.

A photo electric scanning incremental rotary encoder 62 is secured to the lower end of cylindrical housing 30 through bolts 64 and collar 66 such that the rotatable tubular shaft 68 of the encoder 62 be co-axial with shaft 36, the latter being fitted with an extension 70 inserted with a tight fit within encoder shaft 68 and rotatably secured thereto by a spacer 72 and nut 74.

Encoder 62 measures precisely the angle of rotation of shaft 36 with respect to a zero reference which can be selected.

5           Top disk 52 has a central hole 53 which communicates with the inside of tubular shaft 36 and also with the inside of tubular extension 70 for the passage of electric wires interconnecting the several rotary encoders and also the temperature sensors to the  
10           electronic circuits within base 10 as will be described hereinafter.

          The horizontal portion 24 of L-shaped arm 22 forms a tubular beam of approximately square cross  
15           section and its radially inner end is secured to the top disk 52 by bolts 76 with the intermediary of a pad 78. The connection between the top disk 52 and arm horizontal portion 24 is further reinforced by an I beam 80 (See figure 6).

20           As shown in figure 7, the vertical portion 26 of the L shaped arm 22 is tubular, is inserted within the outer end of horizontal portion 24 and is rigidly secured thereto by means of a sleeve 82 and bolts 84. A tubular  
25           shaft 86 is mounted co-axial within vertical arm portion 26 for rotation about a vertical axis by means of vertically spaced upper and lower pairs of ball bearings 88 and 90 respectively, thereby, constituting a second rotary joint 87. A second rotary encoder 92 is secured to  
30           the lower end of vertical arm portion 26 and its rotatable tubular shaft 94 surrounds and is rigidly secured to an extension 96 secured to tubular shaft 86.

          The upper end of tubular shaft 86 carries a top  
35           disk 98 which is secured to a superposed cylindrical support 100.

The intermediate arm 102 (see figures 1, 7, 9 and 10) is connected to the upper end of the vertical arm portion 26 by means of a third rotary joint generally indicated at 104 and which has a rotation axis perpendicular to the rotation axis of the second rotary joint constituted by the shaft 86 and ball bearings 88, 90. Third rotary joint 104 includes a transverse shaft 106 extending across support 100 and mounted in ball bearings 108. Shaft 106 is tightly fitted within the tubular shaft of a third rotary encoder 110, the casing of which is secured to support 100.

Intermediate arm 102 is tubular and fitted at its inner end with a solid insert 112 through which extends shaft 106 which is keyed therein by means of a tapered key 114.

The opposite end of shaft 106 carries a crank arm 116 to which is attached a counter balancing coil spring 118 (see figure 8) the opposite end of which is adjustably attached by means of the threaded telescopic part 120 to the outer end of a downward extension 124 fixed to support 100. The outer end of intermediate arm 102 carries a fourth rotary joint 126, see figure 11, which is similar to the third rotary joint 104 and which is an articulation for an outer arm 128 with respect to the intermediate arm 102 about an axis transverse to both arms.

The fourth rotary joint 126 is fitted with a fourth rotary encoder 129 which is mounted as encoder 110. The fourth rotary joint 126 can be equipped with a counter balancing system including a crank arm 116, a coil spring 118, a telescopic threaded attachment 120 and an extension 124 (See figure 7 and 8).

Referring to figures 1, 11, and 12, outer arm

128 comprises an inner section 128a and an outer section 128b which are coaxial and join at a fifth rotary joint 130. Inner section 128a includes concentric inner and outer tubes 132 and 134 secured to stirrup or support 100a of fourth joint 126 and to a spacer ring 135 and fifth joint 130. Inner tube 132 has an inner tube extension 136 secured to inner tube 132 by a coupling collar 138. Outer tube 140 of outer arm section 128b is rotatable around inner tube extension 136 by means of longitudinally spaced ball bearings assemblies 142. Inner tube extension 136 is terminated by a stud shaft 144 (see figure 12) which is connected by a flexible joint 146 to the shaft 148 of the fifth encoder 150 the casing of which is fixed to axially rotatable outer tube 140 which is extended by an outer tube extension 140a which carries a sixth rotary joint 152 by means of which a probe holder 154 is pivoted to outer tube extension 140a for rotation about a transverse axis. Probe holder 154 carries a touch probe 156 and is secured to a collar 158 which is keyed onto a transverse shaft 160 rotatably mounted by ball bearings 162 in a holder assembly 164 secured to outer tube extension 140a. This holding assembly 164 carries the stator of a sixth encoder 166. The shaft 168 of encoder 166 is connected by a flexible joint 170 to transverse shaft 160. Probe holder 154 is of known construction, it includes a pressure switch which closes to send a signal when probe 156 is lightly pressed against a part being measured. Probe holder 154 and encoders 166, 150, 129, 110 and 92 each require a single data transmitting wire which extends through the hollow arms 128, 102 and 22 and through passages in the joints to be connected to micro-controllers 172.

Thermic sensors 174 are located in the various arms and connected to the micro-controllers 172.

Also, a shock loading alarm system 176 is

located in base 10. This alarm system is of known construction. It stops the operation of the measuring assembly when shock loading exceeds a predetermined maximum. It includes three accelerometers mounted on the base along XYZ axes.

As shown in figure 13, there is one micro-controller 172 for each rotary encoder or angular sensor; each angular sensor feeds data to its own controller. The required number of thermic sensors 174 are also connected to micro-controllers 172. All of the micro-controllers are connected in a network as indicated at 178. Therefore, they communicate with each other by a network protocol and the resulting data is sent to a radio transmitter and receiver 118, which communicates with radio receiver and transmitter 6 at the remote processing station 2.

Each encoder sends two sinusoidal signals which are out of phase to indicate the direction of rotation.

As shown in Figure 14, each micro-controller 172 has a sinusoidal signal amplifier 182 which is connected to the associated angular sensor. The two out-of-phase sinusoidal signals of repeatetivity are cleaned by a signal cleaner 184, then compared by a signal comparator 186, the output of which is sent to a left-right rotation discriminator 188. The output of the latter is sent to an encoder steps counter 190, the output of which is converted from analog to digital in a converter 192. The resulting signal is sent to an arithmetic and processing unit 194 which also receives data from the associated thermic sensor 174.

The output of counter 190 is also sent to a state function register 196, the output of which is connected to unit 194.

The whole micro-controller is fed with regulated tensions through tension stabilizer 198. The output of unit 194 is sent to the network adapter 178 (see also Figure 13). An analogic interface module 200 of converter 192 is connected to signal cleaner 184. This interface is a "sample and hold module" that continuously calculates the average oscillations of the angular sensors.

Three types of standard converters 192 can divide one pulse by 256, 512 or 1024 meaning that for instance, 256 instantaneous values per pulses are stored and converted to a digital value. The resulting digital signals can be averaged in the processing unit 194 or in computer 4 and converted to an angle measurement. Therefore, supposing there are 36,000 pulses sent by one encoder during one complete rotation of 360°, the resulting precision or resolution of the measured angle is multiplied by 256, 512 or 1024 depending on the selected converter 192.

With this apparatus of the invention, it is possible to measure coordinate points up to a radius of about 3 meters and more in any direction.

Since the measuring apparatus is on wheels, this facilitates its manoeuverability and the accessibility to the part being measured.

Since the apparatus can be automatically levelled its measuring precision is not affected by floor irregularities.

Any excessive shock loading of the measuring machine will not cause inaccurate measuring results.

Due to its temperature compensation system,

different portions of the arms system can be subjected to a relatively large temperature gradient without affecting the precision of the measurements, since radio data transmission is used between the measuring machine and the central computing station. Elimination of a cable connecting the machine to the station eliminates possible accidents of someone stepping on the cable, and also, it speeds up the new positioning of the measuring machine.

Since each micro-controller is capable of recording at any time several instantaneous angular position values per pulse emitted by the associated encoder and is programmed to calculate the average of said several values, this minimizes any erroneous reading which could be produced by possible mechanical vibrations.

In addition, each micro-controller can be selectively set to zero by the operating software and be given a predetermined value that suits any potential application. This way, proper values can be given to each angular sensor which can be properly converted, resulting in extensive calculating time saving in the arithmetic processing unit 194, and also in the computer 4.

The radio link between the measuring machine and the computer station 2 eliminates an interconnecting cable which normally is composed of 48 wires for the encoders plus about 12 wires for the temperature sensors. By using a sample and hold module 200 in the analog to digital converter 192, all instantaneous values of all the sensors can be read at the same time, resulting in a most accurate reading, this being in addition to the fact that 256 instantaneous sampling of the angular sensor data output is effected for each pulse sent by the rotary encoder.

The instantaneous tension value is analyzed by the converter 192 which normally is a 16 bits converter and conversion of the data into an angle is done using a matrix that includes a transformation function. The  
5 matrix is a single chip in the computer 4. If necessary, this computer 4 and the radio communication system can be released of the duty of calculating an average of the values already read, since this calculation can be done by each micro-controller.

10

It is noted that each micro-controller reads and transmits the temperature of at least one of the two arms interconnected by a rotary joint where the angle is read whereby proper temperature compensation corrections  
15 can be made even if the arms of the measuring machine are subjected to a large temperature gradient.

15

Since the computer 4 commands all the micro-controllers at the same time an instantaneous average of  
20 all the angular values can be obtained.

20



## I CLAIM

1. An apparatus for measuring the XYZ coordinates of a point on a part to determine its position in space comprising a movable measuring assembly and a remote processing station, said measuring assembly comprising a base, a probe for engaging said point, serially coupled rigid arm members and rotary joints coupling said base to said probe and permitting said probe to be moved in space relative to said base, each joint including two relatively rotating parts, a rotary encoder for each joint, for measuring the rotation angle of one part relative to the other part of the joint, said encoder sending an analog sinusoidal signal of N pulses per complete rotation, a micro controller for each encoder including an analog-to-digital converter and a processing unit to generate a digital signal indicative of an instantaneous rotation angle, network means interconnecting all of said micro-controllers and means to transmit to said remote processing station data representing the simultaneous readings of all of said encoders, said remote processing station including a computer for receiving the transmitted data and processing the same to transform the data into measured coordinates from a reference point.

2. An apparatus as defined in claim 1, wherein said measuring assembly further includes a radio frequency transmitter connected to all of said micro-controllers via said network means, the latter including wire means extending along said arms and interconnecting all of said micro-controllers with said radio transmitter, said processing station including a radio receiver connected to said computer whereby a radio link is established between the station and the movable assembly through which all of the measurement data is transmitted.

3. An apparatus as defined in claim 1,  
wherein each controller further includes sinusoidal  
signals sampling and holding means and means to calculate  
sinusoidal signal averages of successive data inputs and  
5 feeding said averages to said analogic to digital  
converter.

4. An apparatus as defined in claim 2,  
wherein each controller further includes sinusoidal  
10 signals sampling and holding means and means to calculate  
sinusoidal signal averages of successive data inputs and  
feeding said averages to said analogic two digital  
converter.

15 5. An apparatus as defined in claim 4,  
wherein said base is mounted on wheels for displacement  
on a floor or the like and further including base  
levelling legs carried by said base and means for  
automatically actuating said legs to level said base.

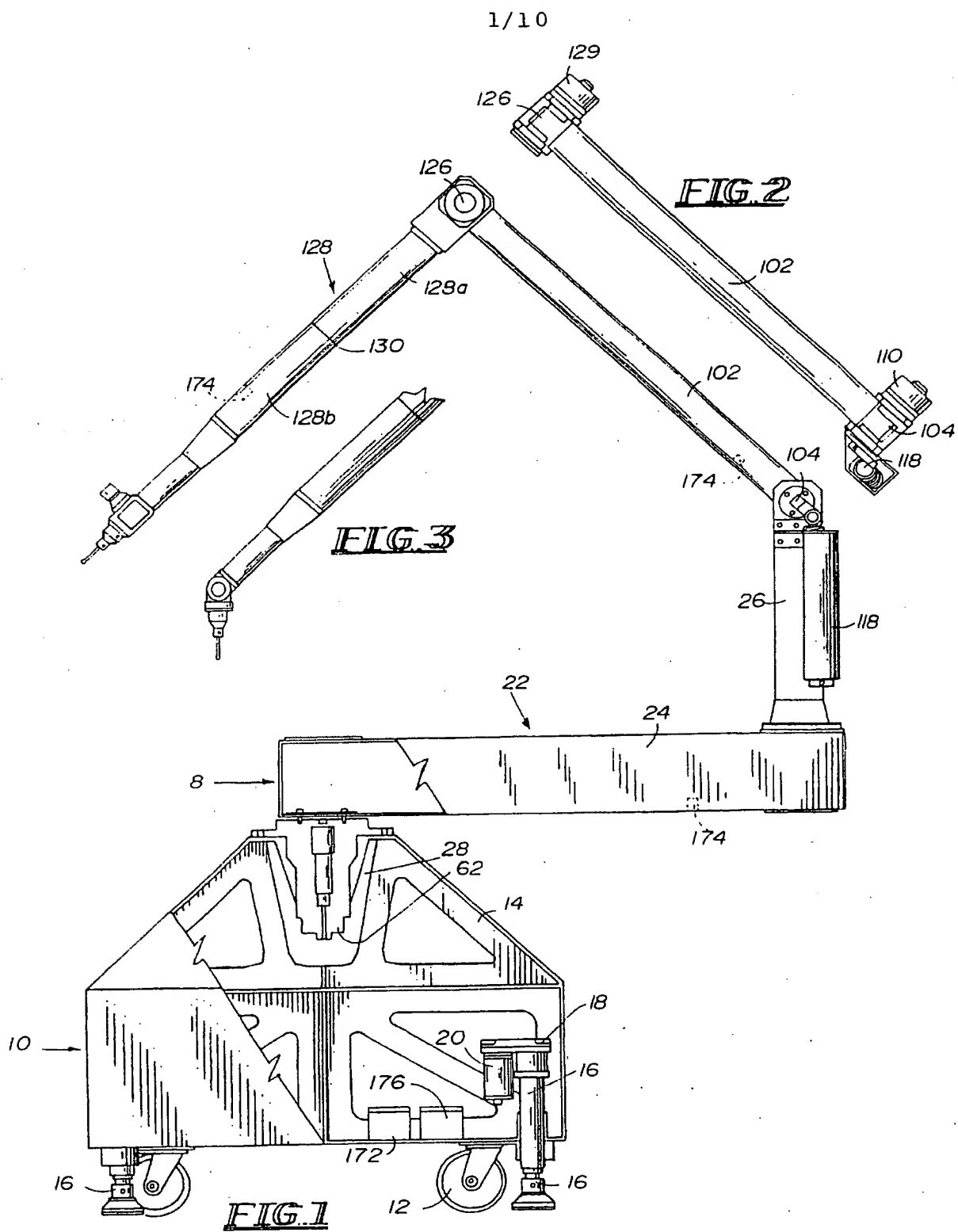
20 6. An apparatus as defined in claim 4,  
further including temperature sensors for each arm member  
connected to each micro-controller, said micro-  
controller is programmed to be capable of calculating  
25 temperature correction factors of each member and further  
more transmitts the adjusted values to the central  
computer unit through the said radio transmitter.

7. An apparatus as defined in claim 6,  
wherein said base is equipped with an alarm system  
30 sensitive to shock loading of said base and stopping the  
operation of measuring assembly when shock loading  
exceeds a predetermined maximum.

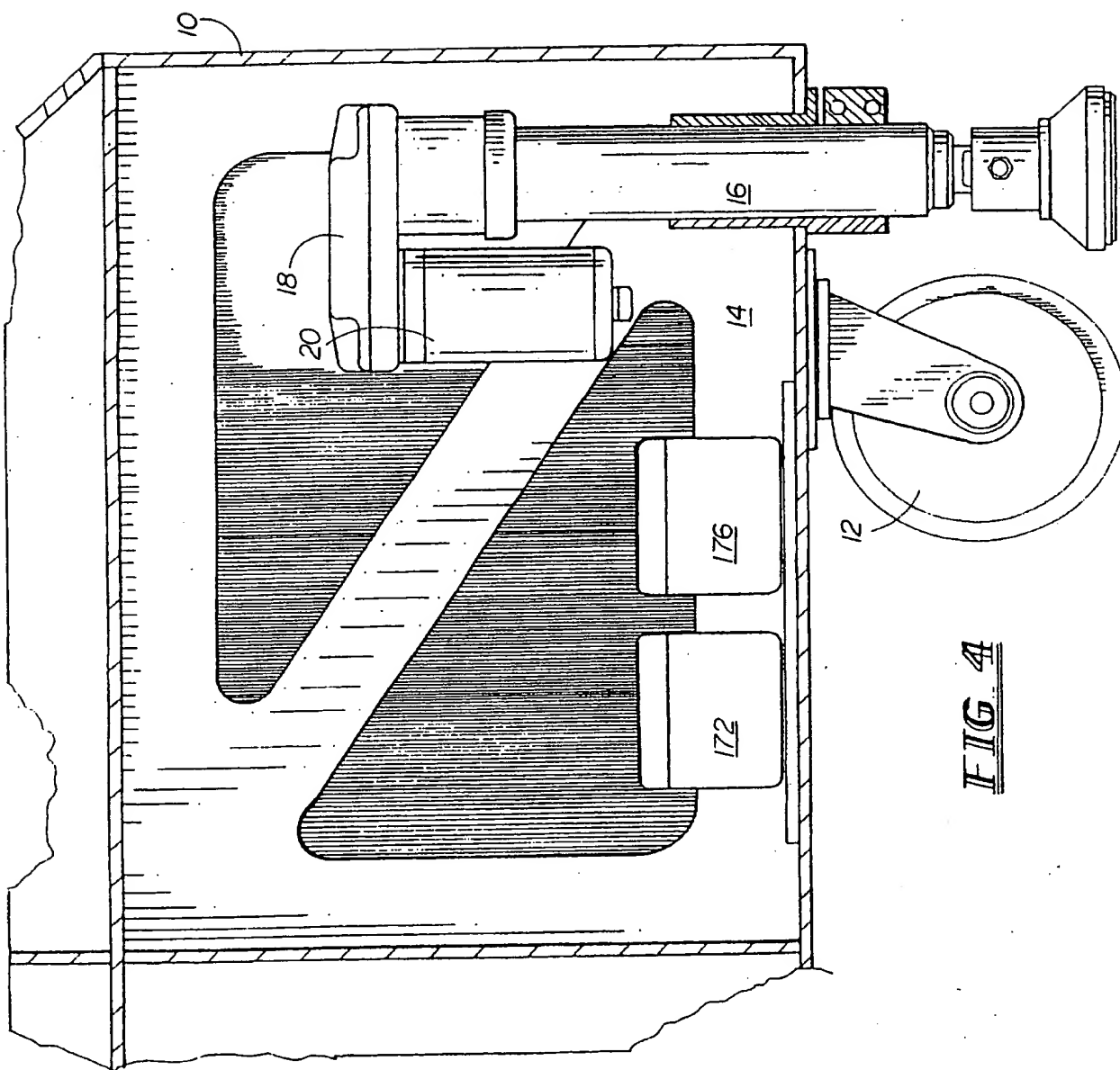
8. An apparatus as defined in claim 7,  
35 wherein said shock loading system includes three  
accelerometers mounted on said base along XYZ axes.

9. An apparatus as defined in claim 3, wherein said arms are of decreasing length and said encoders send a decreasing number of pulses per complete rotation from said base to said probe.

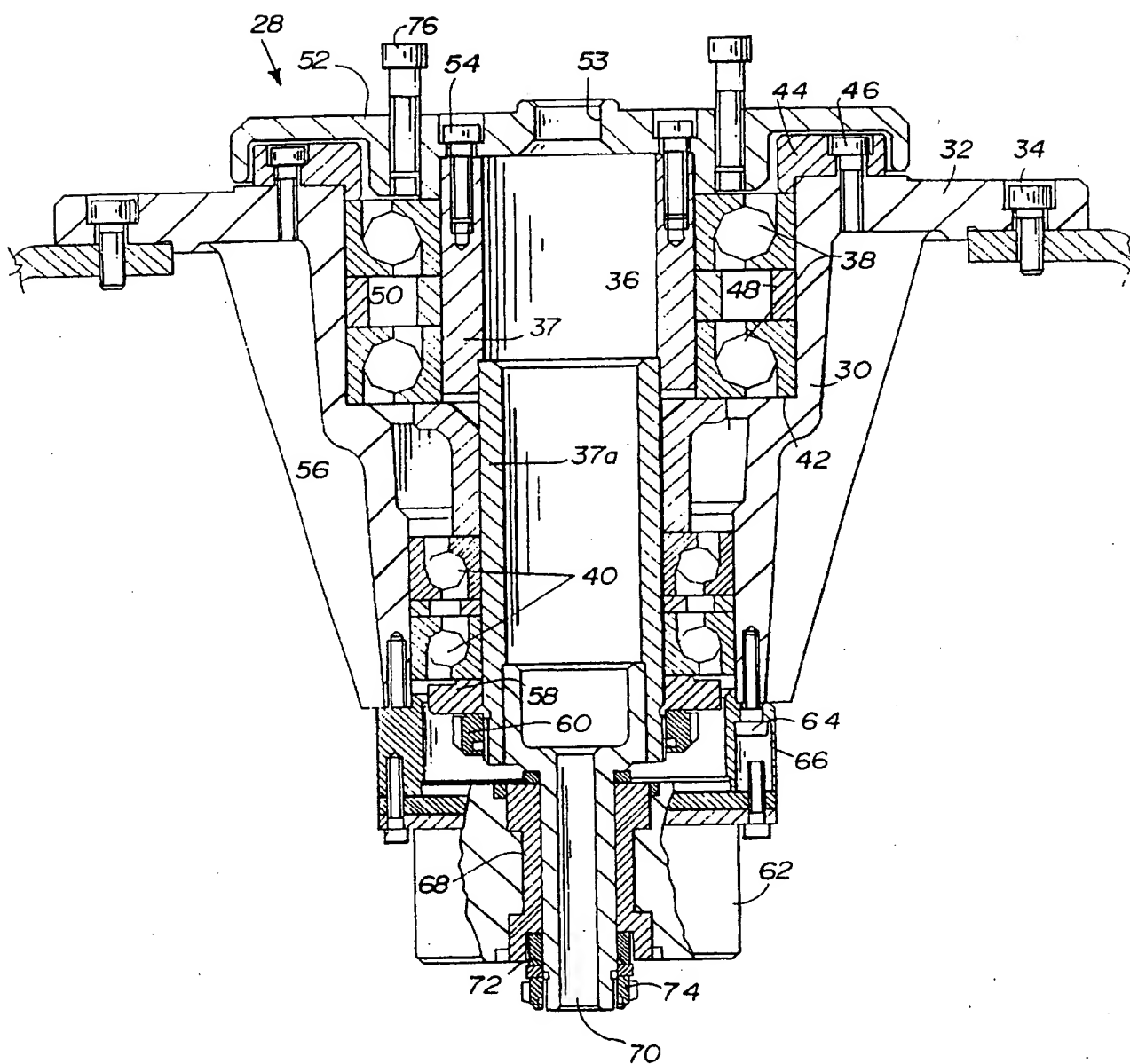
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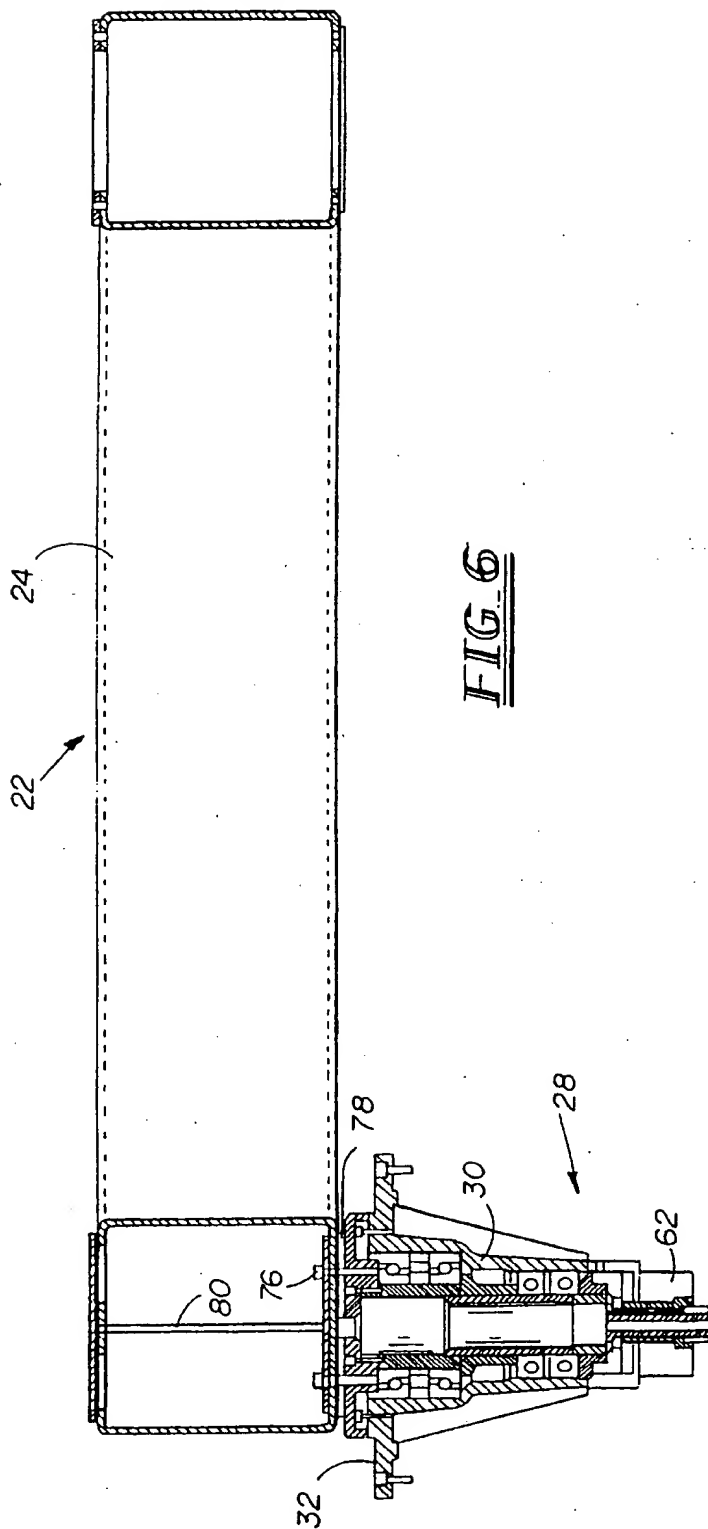
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**FIG. 4**

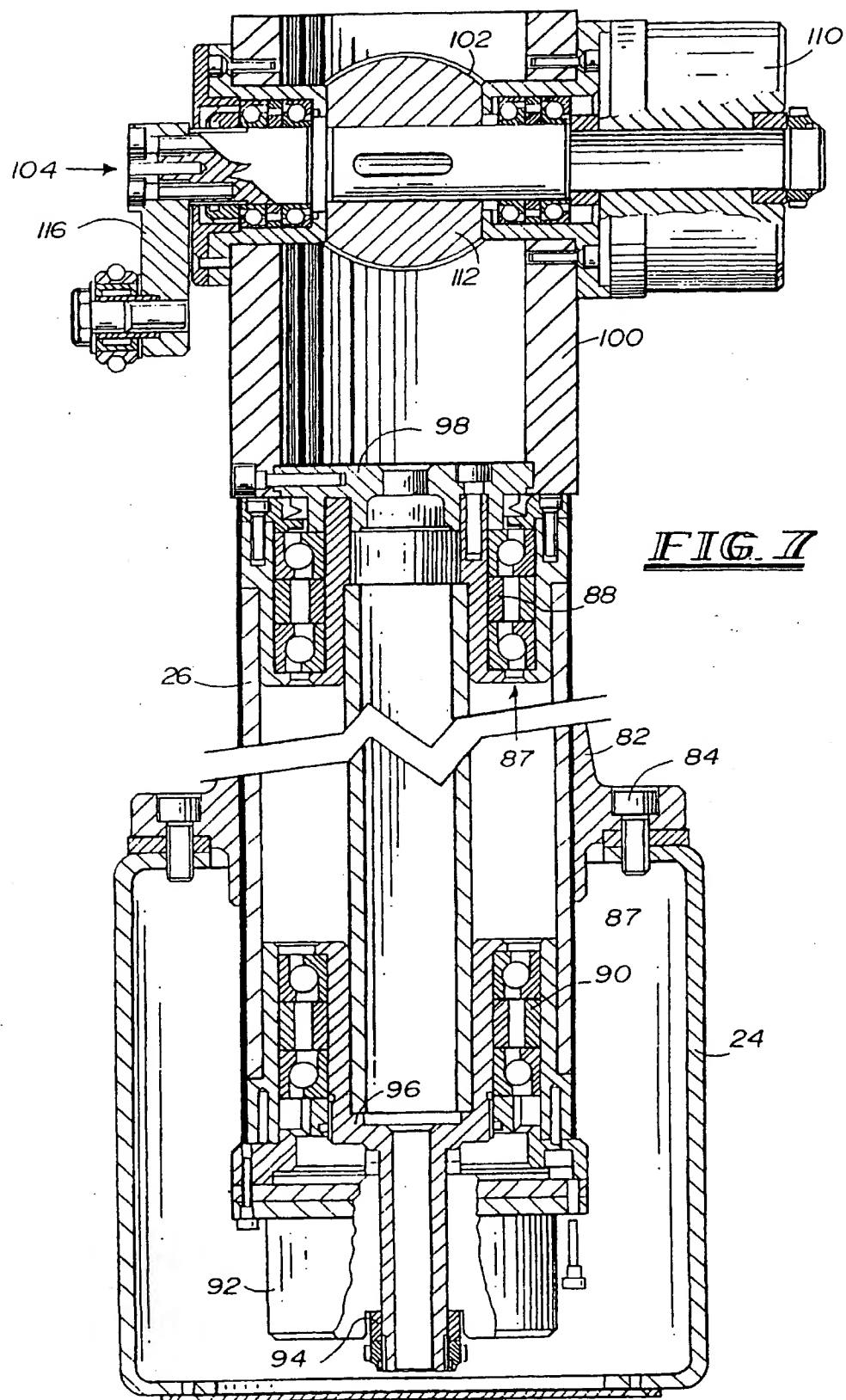
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**FIG. 5**

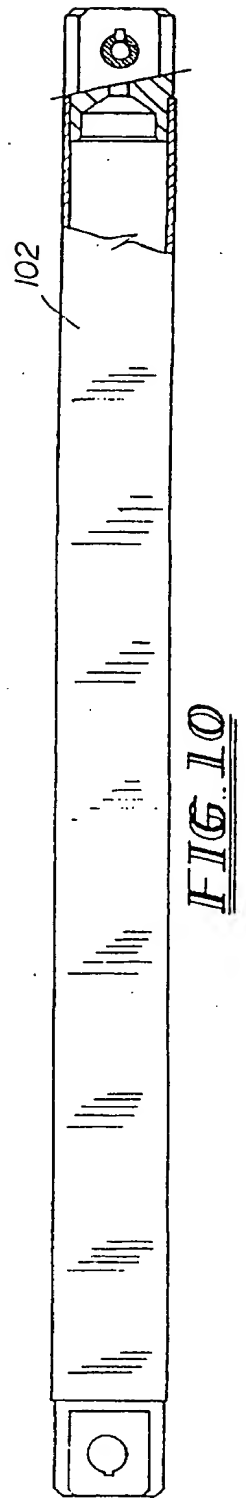
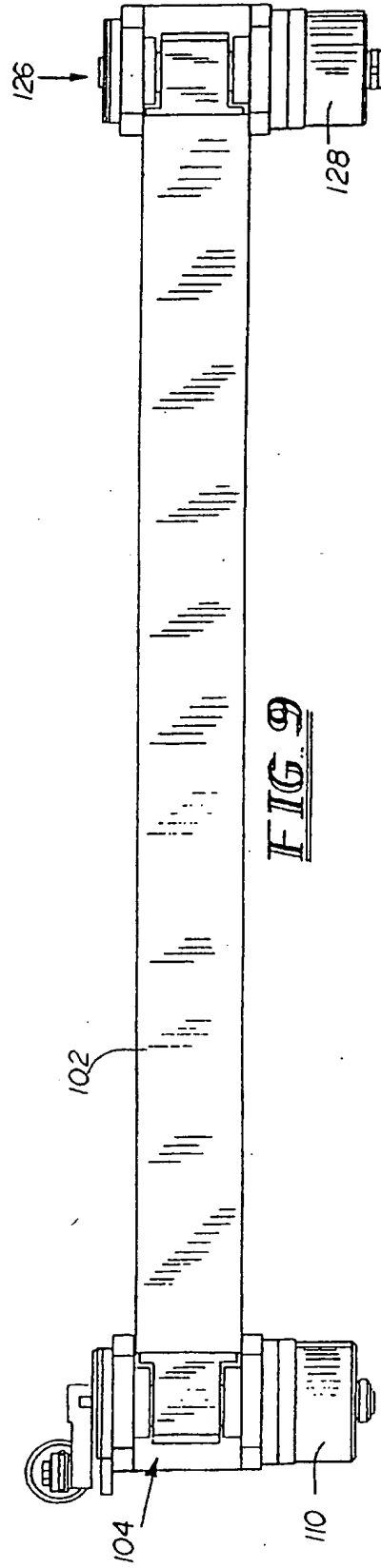
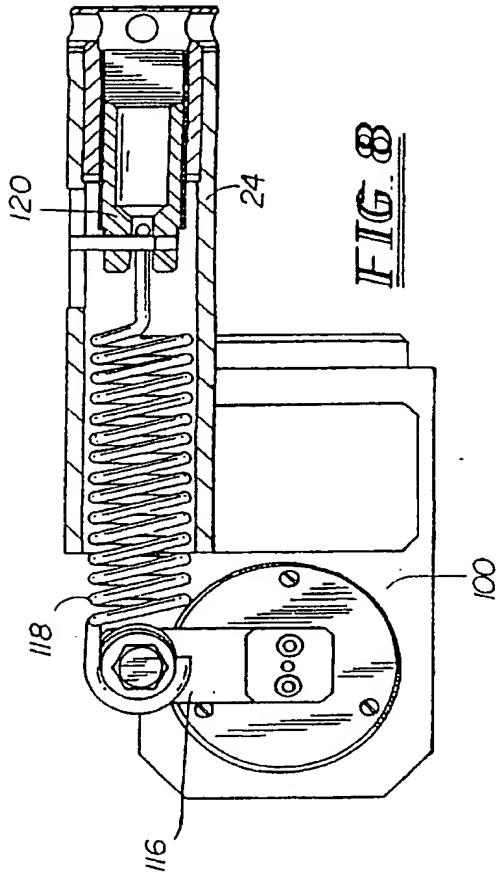
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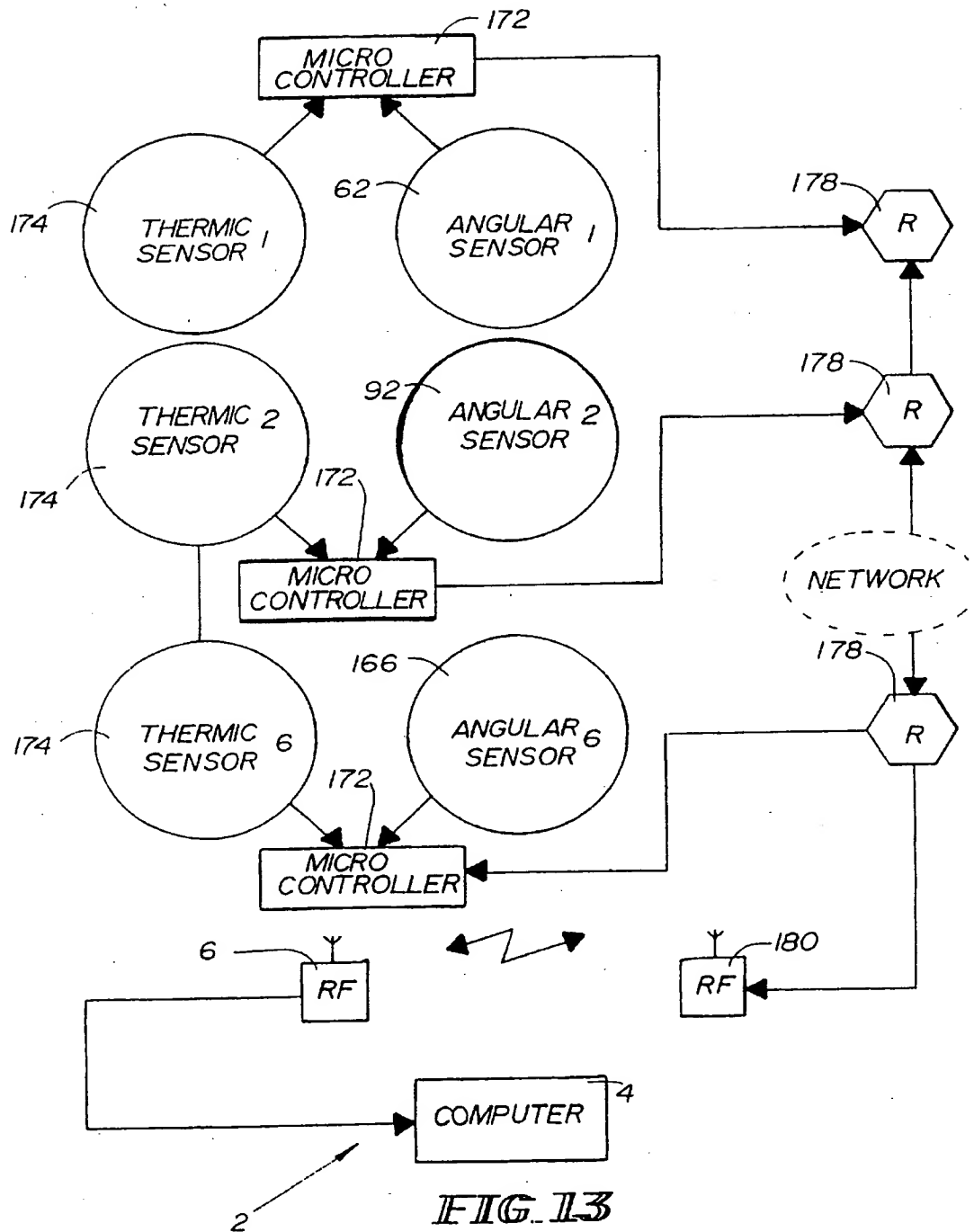
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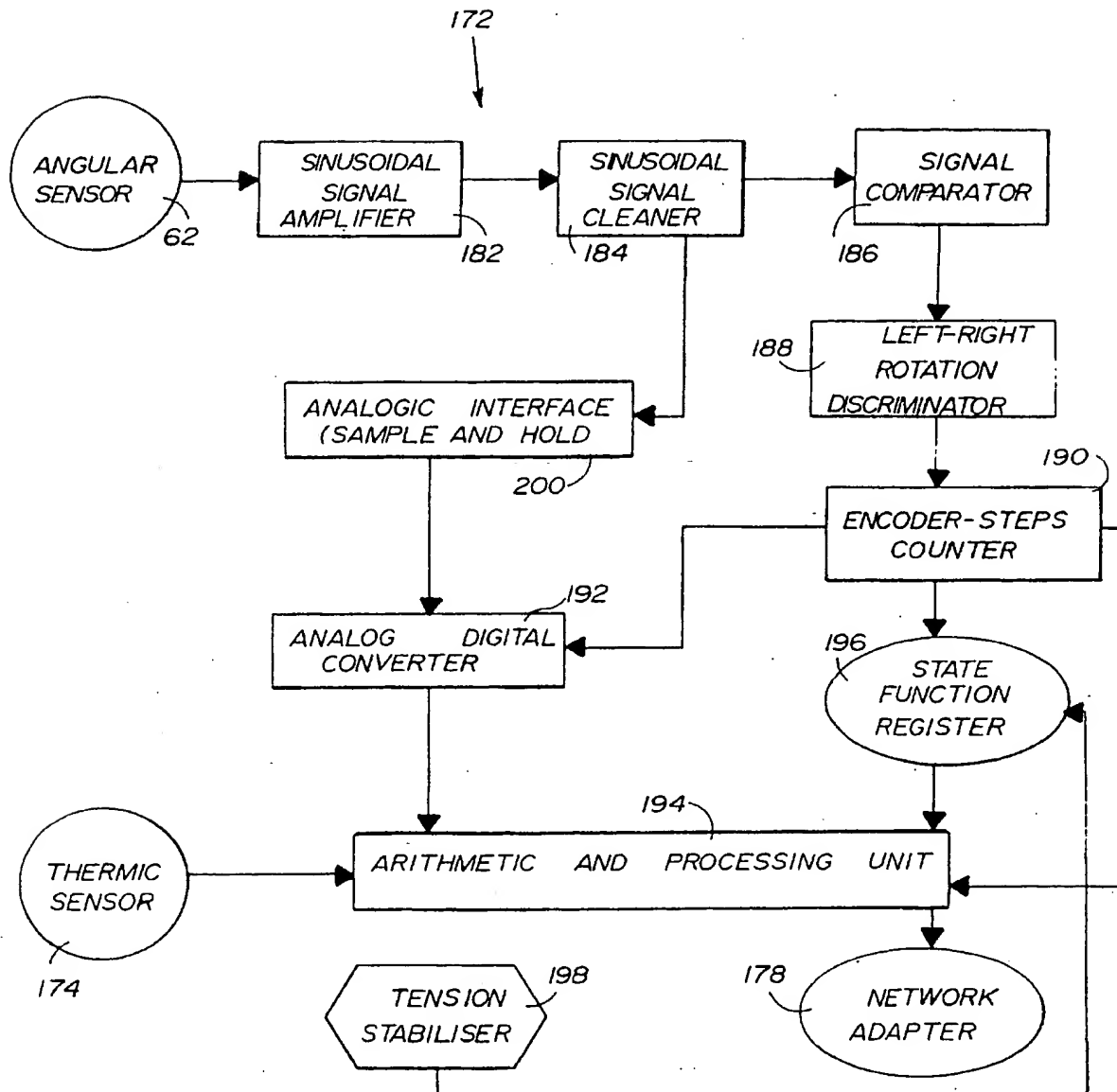


FIG. 14

# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/CA 97/00103

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 6 G01B21/04

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
IPC 6 G01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 44 03 901 A (FARO TECHNOLOGIES, INC.) 25 August 1994 * see introduction * see column 4, line 44 - column 8, line 56; figures 1,4-9B see column 10, line 25 - column 12, line 22; figure 13 ---	1,3,5,6, 9
X	DE 44 33 233 A (ROMER SARL) 13 April 1995 see column 4, line 45 - column 6, line 25; figure 1 see page 7, line 53 - page 8, line 18; figure 3 --- -/-	1,3,5

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

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# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/CA 97/00103

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
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